The monitoring electronics of the laser calibration system in the Muon g-2 experiment

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ABSTRACT

The new Muon g-2 experiment at Fermilab (E989) will measure the muon anomaly a_μ = (g_μ -2)/2 to an uncertainty of 16 x 10^{-11} (0.14 ppm). The experiment is running with a positive muon beam. The decay positrons are detected by 24 electromagnetic calorimeters placed on the inner radius of the magnetic storage ring. As the gain fluctuation of each calorimeter channel must be corrected to a few parts in 10^4, a state-of-art laser calibration system has been realized which provides short laser pulses to the calorimeters. The monitoring of these light signals is done by specific photo-detectors read by a specialized Monitoring Electronics, which is organized in devoted crates and performs the full data acquisition of the calibration signals starting from pre-amplification, then digitization and finally transfer of the information. Here we describe few key elements of the whole system, namely the single readout channel of the Monitoring Board.

1. Laser calibration system

The Laser Calibration System, part of the E989 experiment [1] presently running at Fermilab, consists [2] of a laser control board [3]

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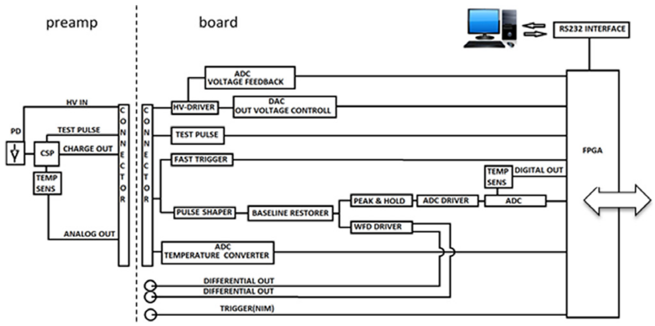

Fig. 1. Single readout channel: Preamplifier and MB. The output of the baseline restorer is doubled, so the signal is digitized by both a custom WFD (12 bit, 800 MHz) and by a 14 bit ADC (AD9244).

able to drive 6 lasers which, via a distribution system (diffuser, 4 calorimeter/diffuser), provide light calibration signals to the calorimeters. The light arriving at the calorimeters simulates the light production initiated by the decay positrons within the calorimeters. The light provided by the lasers is monitored at source through 6 Source Monitors, then downstream of the distribution by 24 Local Monitors. The monitored calibration pulses are translated into electrical pulses by suitable detectors, then measured by the Monitoring Board (MB).

2. Monitoring electronics and DAQ

In the Source Monitor (SM) a fraction (20%) of the laser light enters into an integrating sphere, then it goes to 3 photo-detectors, namely 2 PIN diodes (PID, S3590-18) and one photomultiplier (PMT, H11900), all from Hamamatsu. The PMT is also coupled to a radioactive Americium-241 source, embedded in a sealed NaI crystal, whose α particles act as an absolute reference source through scintillation light in the crystal. In the Local Monitor (LM) a fraction (few %) of the light exiting a diffuser, comes back to the laser room through a 25 m-long fiber and illuminates directly two PMTs; also a fiber coupled to a fourth port of the integrating sphere feeds the two PMTs with a tiny portion of SM light, therefore any relative change between the two signals seen by the LM PMTs is due to the distribution system. Specific electronics has been designed to read, process and digitize the signals coming from the SM and LM photo-detectors (see Fig. 1).

2.1. Single channel of monitoring electronics

The signals from photo-detectors are preamplified, then processed by the MB which performs filtering and digitization of the signal. The MBs are hosted in custom crates containing up to 12 boards, each board has 3 readout channels whose photo-detectors are managed by the board itself.

The preamplifier. The pre-amplification design has required a careful coupling to the sensor and attention to noise reduction due to the dark current. The used S3590-18 PIN has an output capacitance ranging in tens of pF depending on the applied bias voltage. The signal from PIN devices are expected to vary from fraction of pC to several pC, with a rise time of about 10 ns and a fall time of hundreds of ns. The conversion gain (G) of the preamplifier was set to 800 mV/pC. A capacitor next to the channel input, chargeable by a FPGA process, allows self-calibration of the electronic channel; the calibration signal is stable at better than 10^{-4}/°C. At the arrival of the signal the preamplifier provides also a fast trigger which mainly identifies the asynchronous Am signal with respect to the beam time. For the PMT signal the gain is set to 200 mV/pC, while the preamplifier circuit is essentially the same as for PIN.

The pulse shaper and the baseline restorer. The pulse shaper circuit transforms the output from the preamplifier, which has a long tail (about 20 ms), to a semi-Gaussian shape around the peaking time that reduces the pulse duration, avoids overlap and increases the sustainable signal rate; to optimize the pulse stability the signal width was set at 600 ns. Next stage, the baseline restorer, is meant to avoid that baseline shift causes an uncertainty in the peak determination. The adopted scheme limits the pulse rate to a few tens of kHz. The output of the baseline restorer is doubled and one signal, made fully Gaussian with 600 ns width, is sent in a suited differential form to a custom WFD (12 bit, 800 MHz, hosted in a μTCA crate) which is part of the main DAQ.

Peak tracking and ADC conversion. The other signal at the output of the baseline restorer goes to a peak seeking circuit, which tracks and holds for long enough the peak level (P&H), which in turn is converted through ADC. The chosen ADC is the AD9244 from Analog Device, it has a 14 bit accuracy at 65 MSPS data sampling. The differential input ranges from 0. to 2.0 V. The Effective Number of Bits (ENOB) is 11.7. The voltage drop rate of the P&H circuit is less than 30 μV/μs. Considering an acquisition time of about 400 ns the voltage drop is contained within 12 μV, that is well below 1 bit.

The FPGA control block. The signal processing of the photo-sensors is managed by the FPGA. There is one FPGA per channel then 3 FPGAs on a board. The control block manages also the bias voltage for the PINs and the reference voltage (HV) for the PMT; the voltage is settable by an 8 bit DAC and the operational voltage can be read back. For the PIN an EMCO module is used which is capable of relative voltage variation of few 10^{-6}/°C. For PMT the reference voltage (0–1 V) is generated by the board itself and is readout back through a shunt resistor. There are three temperature sensors per channel: one located on the board (digitized value), another on the preamplifier board (analog signal) and the environmental temperature through an external sensor (digitized value). All sensors have an accuracy of 0.1 °C and their readout is on request. The MB performs calibration of the 3 electronic channels by injecting a known charge at the preamplifier input, this process is operated through a 14 bit DAC. The MB activity does not require any external trigger; in fact readout is triggered when the signal amplitude is greater than a fixed threshold (Th1), then signal processing starts and data are stored in a local FIFO. On the PMT channel is implemented a second threshold (Th2) which allows distinction between laser and Americium signals. Both thresholds are wired, implemented with high precision components. The FPGA of each channel builds the data frame for each pulse, which is made of header (cycle (machine) number, temperature and bias voltage information), then the sequence of pulse number, pulse time (accuracy 10 ns) and the ADC value, finally a footer information. A fourth FPGA on the board reads the data frames from the three front-end FPGA, performs the event building at board level and sends data to the crate controller, which in turn performs the complete event building and provide data to the storage system [4]. The MB has also a slow interface (RS232) for debugging purposes.

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